A COMPUTER SIMULATION FOR MOTORCYCLE RIDER INJURY EVALUATION IN COLLISION

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Paper Number 05-0309

ABSTRACT

Honda is developing a computer simulation technology designed to predict injury levels from a impact to when an MATD dummy strikes the ground during testing. Correlation of results of full scale impact tests and computer simulation specified in ISO/CD 13232, were examined. As the result, it was validated that the computer simulation can predict injury levels from an impact to when a dummy strikes to the ground. The performance and effectiveness of an airbag system for a GL1800 in 200 impact configurations and 400 cases specified in ISO/CD 13232 was evaluated by using the computer simulation. As a result, the total average benefit was 0.048, risk was 0.004. The highest average net benefit appears at the range from 20 to 25 m/s in the relative impact speed.

INTRODUCTION

Honda has been researching ways to increase the protection of motorcycle riders in accidents since the 1960s[1]. In recent years, research has been conducted on the possibility of motorcycles equipped with an airbag system as a means of enhancing rider protection. In the research, an airbag system including impact detection sensors was manufactured on an experimental basis and mounted on a GL1500, a large touring motorcycle of Honda. Impact tests were conducted using the motorcycle. The results obtained were reported at the ESV conferences in 1998[2], and 2001[3]. One of the findings from the research was that the changes in measured values of injury to the dummy most often affected by the airbag occurred at impact with the ground. ISO/CD 13232[4] contains test and analysis procedures for research

evaluation of rider crash protective devices fitted to motorcycles. It specifies that the performance of rider crash protective devices should be evaluated by computer simulation in addition to impact tests using actual motorcycles (hereinafter referred to as full scale impact tests). The computer simulation is intended to cover a 0.5 second time period, from the start of impact through dummy impact to the opposing vehicle (hereinafter referred to as primary impact sequence). We determined, however, from consideration of the results of the tests described above that it would be necessary to evaluate the injury from the start of impact to when the dummy strikes the ground.

Therefore, we conducted tests to establish a computer simulation technology that allows for the prediction of injury levels from start of impact to when a dummy strikes the ground (hereinafter referred to as entire impact sequence). For this analysis, an explicit method FEM software, which is easily expresses shapes and reproduces deformations of vehicles, was selected. In the FEM software, mesh sizes, which largely affect the calculation time and the accuracy of the calculation, were studied and decided. Models of motorcycle, airbag, dummy and opposing vehicle were created and computer simulation calculations were performed. From these calculations, the compliance of dummy motions at the time of dummy strike to the ground was evaluated using the dummy head velocity and torso angles.

As a result, a computer simulation method reproducing testing results with high accuracy was developed. At the same time, a very effective method of shortening the calculation time was contrived. These results were reported to 2003SETC[5]. Using the aforementioned computer

simulation method, the research was carried out to evaluating the injury index from the start of impact to the point in time when the dummy struck the ground. Correlation of the results of full scale impact tests and computer simulation, as specified in ISO/CD 13232, covering seven impact configurations and twelve cases, were examined. As a result, it was confirmed that the computer simulation can predict injury index from the start of impact to when the dummy strikes the ground.

EVALUATION OF INJURY INDEX TO WHEN DUMMY STRIKES GROUND

Developing the computer simulation method reproducing dummy motions with high accuracy, and one which predicts injury levels in the entire impact sequence was carried out. The seven impact configurations specified in ISO/CD 13232 were employed to verify the accuracy of the computer simulation research. The impact configurations are shown in Fig.1. Basically, simulations were conducted both with an airbag and without an airbag. However, incase of with-airbag in No.1 and No.4 of the impact configurations shown in Fig.1 were omitted from the correlation simulation results and full scale test results because the airbag did not deploy in the full scale tests in these configurations. Computer simulations for examination of the correlation were conducted with twelve cases in seven impact configurations. The impact speed of the full scale tests was set at a higher level than that defined in ISO/CD 13232, to evaluate under more sever conditions. The impact speed in the computer simulation was also set at the same speed as the full scale tests.
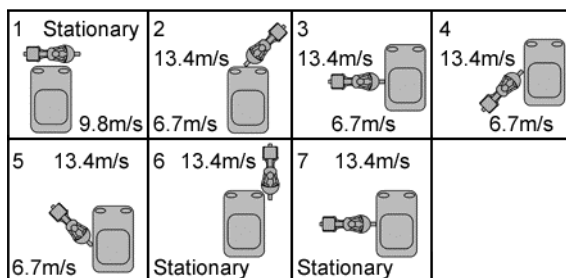

Figure 1. Full scale impact test configurations

Model Creation Methods

Motorcycle Model

In the previous study reported in 2003SETC, the motorcycle model used to validate dummy motion was the GL1500, a large touring motorcycle. The motorcycle, however, was changed from the GL1500 to the GL1800 in the subsequent research. In the computer simulation, therefore, a model of the GL1800 motorcycle was created. The motorcycle model was created using the procedure reported in 2003SETC. The whole of the motorcycle model was created as a deformable body for enhancing the calculation accuracy. The motorcycle model is shown in Fig.2.

Opposing Vehicle Models

Models of opposing vehicles were also created in accordance with the diversification of impact configurations. Because the rigid parts of opposing vehicle model are highly effective for shortening the calculation time, parts with no contact with the motorcycle and dummy and with no deformation employed the rigid model. Four kinds of opposing vehicle models were created, changing rigid parts. The models were used properly in accordance with the impact configurations. Figure 3, 4, 5, and 6 show the opposing models created. Opposing vehicle, HONDA ACCORD 4-door, 1998 to 2001 model, of Japanese specification is shown in Table 1.
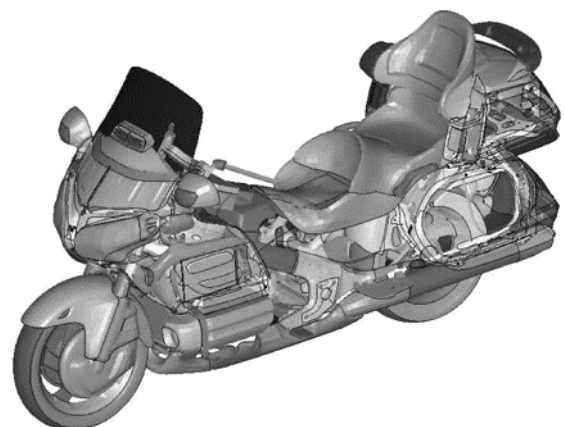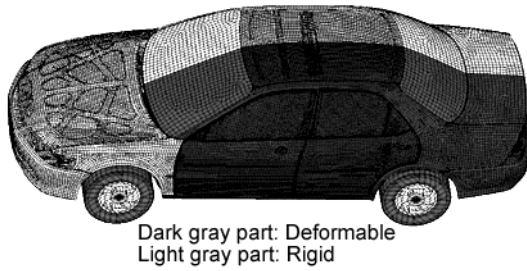

Figure 2. Motorcycle model
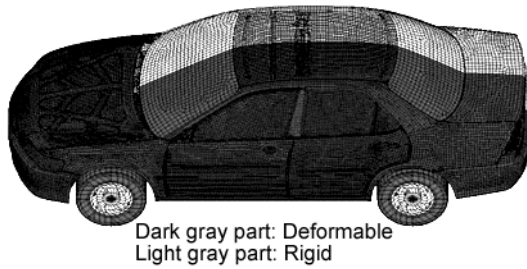
Figure 3. Opposing vehicle model for side impact

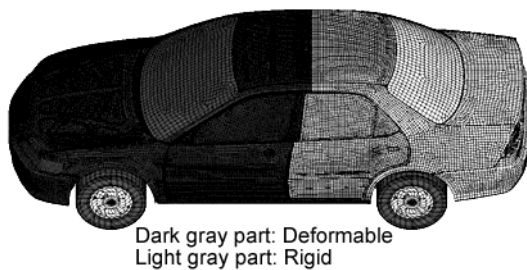**Figure 4. Opposing vehicle model for front-side impact**
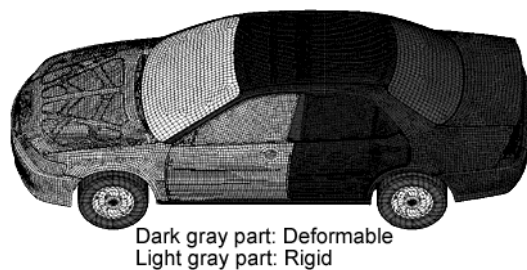

Figure 5. Opposing vehicle model for front impact

Figure 6. Opposing vehicle model for rear impact

Table 1 Specifications of opposing vehicle

Manufacturer	Honda
Model	Accord, Japan
Year	1998-2001
Mass	1300 kg (average)
Overall length	4635 mm
Overall width	1695 mm
Overall height	1420 mm
Wheelbase	2665 mm
Engine displacement	1997 cm³

Dummy Model

Dummy models were based on the hybrid III 50 percentile model for LS-DYNA[6]. They were adjusted to MATD dummy specifications as defined in ISO 13232. Since the evaluation method of injury index of the neck, undefined in ISO 13232, was defined in ISO/CD 13232, a neck model was created faithfully based on ISO/CD 13232. Created models of the neck are shown in Fig.7. The bending characteristics of the neck model were adjusted to conform with the static and dynamic characteristics defined in ISO/CD 13232. The results of static correlation are shown in Table 2. Dynamic characteristics of the neck model such as extension, flexion, lateral and torsion are shown in Fig.8 to Fig.18.

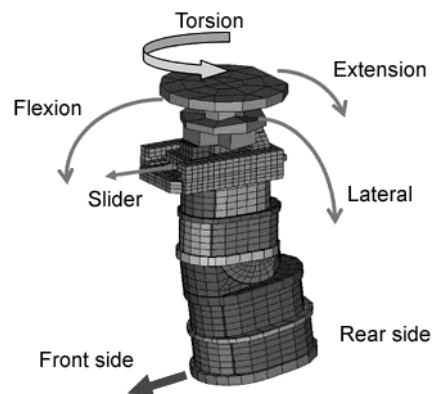As a result of this research, we determined that the model was usable as the neck model for simulation.

Figure 7. Neck model of MATD (ISO/CD 13232)

Table 2 Neck static characteristics of MATD model

Characteristics	Load	Required value	CAE model
Flexion angle	20 kgf	17.6±2.6 deg	15.9 deg
Slider displacement	20 kgf	14.0±3.0 mm	13.8 deg
Extension angle	20 kgf	30.9±4.6 deg	27.7 deg
Lateral angle	20 kgf	28.7±4.3 deg	25.8 deg
Torsion angle	3.2 kgf	41.5±6.2 deg	43.6 deg

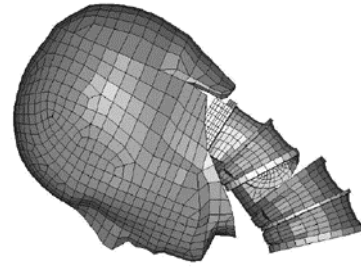**Figure 10. Dynamic flexion position**
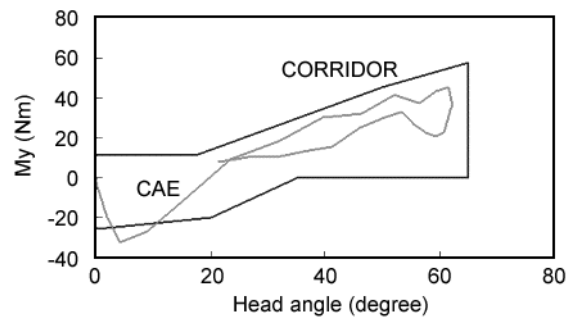
Figure 11. Dynamic flexion bending moment vs. head angle

Figure 8. Dynamic extension position

Figure 12. Dynamic flexion neck angle vs. head angle

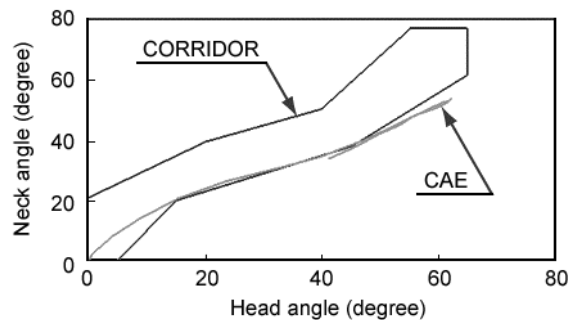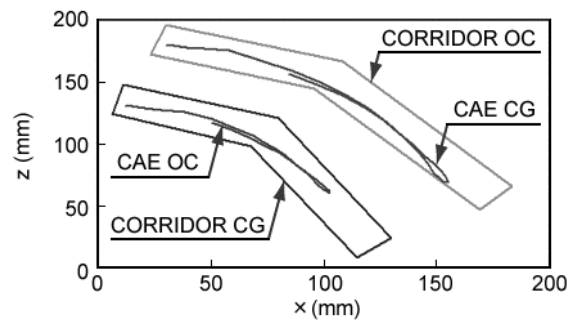**Figure 9. Dynamic extension moment vs. head angle**

Figure 13. Dynamic flexion occipital condoyle and head center of gravity position
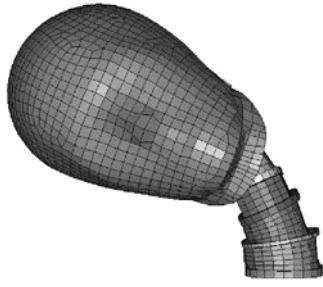
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Figure 14. Dynamic lateral position
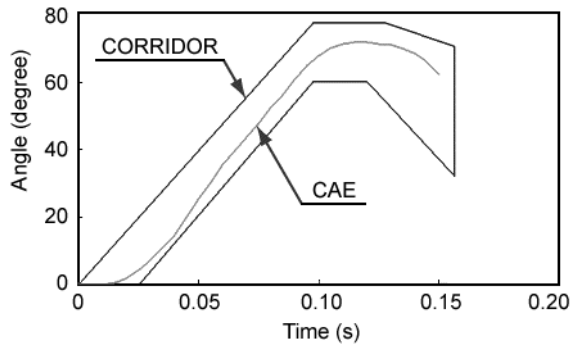

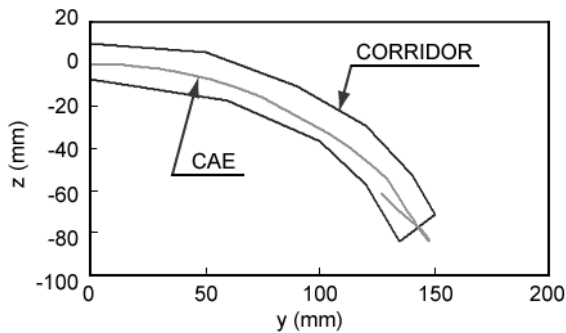**Figure 15. Dynamic lateral head angle vs. time**

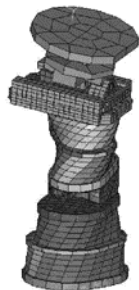**Figure 16. Dynamic lateral head center of gravity position**

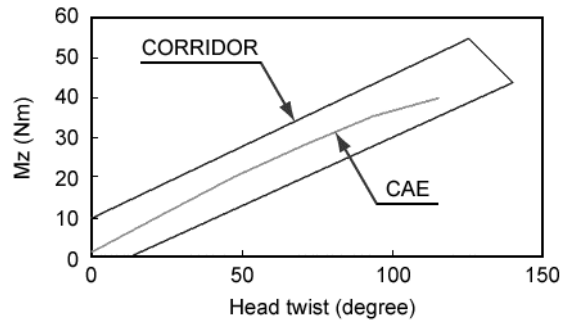**Figure 17. Dynamic torsion position**

Figure 18. Dynamic torsion stiffness

Airbag Model

An airbag model was created based on the airbag redesigned for GL1800. The V-shape of back of the airbag to hold the rider and the connecting and supporting belts from the back of airbag to the motorcycle frame were faithfully modeled. The computer simulation model of the airbag mounted on the model of GL1800 is shown in Fig.19.

Methods of Improving Accuracy of Models

Each model created requires high accuracy to enable the evaluation of injury index in entire impact sequence.

As the first step for that, parts predictable of deformation in impact were faithfully modeled to simulate the actual test vehicles and motorcycle.

As second step, tests under simple conditions such as the unit test defined in ISO/CD 13232 and the rigid barrier impact tests using motorcycles and opposing vehicles were conducted. Simulation models and some calculation factors were adjusted to conform to the actual tests with high accuracy.
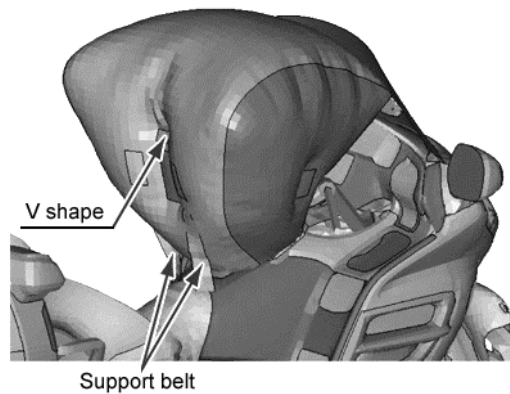

Figure 19. Airbag model

As the final step of validation, model accuracy and some calculation factors were improved by correlation with the test results of 12 test cases using seven impact configurations defined in ISO/CD 13232. Some factors that are not in the simple unit tests or the rigid barrier tests are in the full scale tests, which includes complex phenomenon. Factors such as friction properties as well as detail structural parts of the motorcycle and the opposing vehicle that had been eliminated in prior simulation were added to models of the motorcycle and the opposing vehicle. With respect to these models, the accuracy of the reproducing motion and deceleration of motorcycle and dummy with the seven impact configurations was enhanced. Simulation results of impact configurations of No.3, No.5 and No.7, shown in Fig.1, in which the motorcycle collides with the side of the opposing vehicle, were examined, and the accuracy of models of the side of opposing vehicle and frontal part of motorcycle were enhanced. Next, using impact configuration No.2, shown in Fig.1, in which the motorcycle collides against the front of the opposing vehicle, the accuracy of model of the front part of the opposing vehicle was enhanced. In impact configurations No.4 and No.6, shown in Fig.1, the accuracy of models of the front side of the motorcycle and the opposing vehicle were enhanced, while in the impact configuration No.1, the accuracy of the model of the side of motorcycle was also enhanced.

Correlation of Evaluated Injury Index

The correlation was verified using the injury index of the dummy with 12 test cases using seven impact configurations. The head injury index, values of HIC in the primary impact sequence are shown in Fig.20; values of HIC after the primary impact sequence to the point in time when the dummy strikes the ground (hereinafter referred to as secondary impact sequence) are shown in Fig.21. The r^2 correlation coefficient in the primary impact sequence and in the secondary impact sequence is 0.94 and 0.77, respectively.

Figure 22 shows the maximum compression ratio on the chest in the primary impact sequence. Because the airbag receives the primary impact,

this is an important factor. The r^2 correlation coefficient was 0.62.

Table 3 shows a comparison between the full scale test results and the simulation results for the fracture of leg bones and knee dislocation. The conforming rate of the test results and the simulation results was 96% in femur and 100% in knee and tibia.
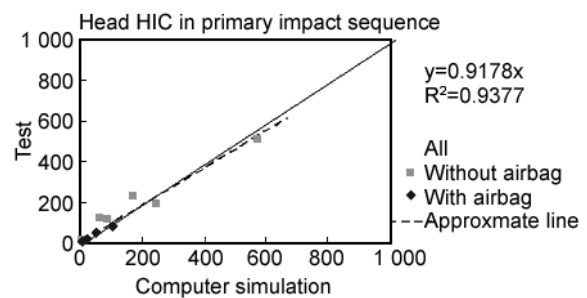

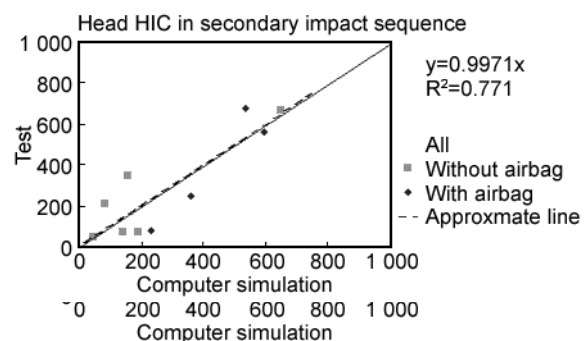**Figure 20. Correlation of HIC at primary impact sequence**

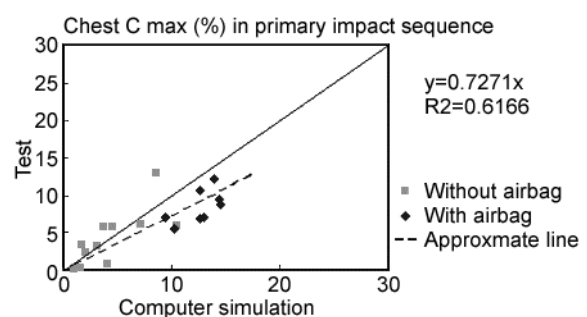**Figure 21. Correlation of HIC at secondary impact sequence**

Figure 22. Correlation of chest sternum compression at primary impact sequence

Table 3 Correlation of leg injury for entire impact sequence

Fumurs		Full scall tests		Present collect
		Fracture	No fracture	
Simulations	Fracture	0	1	96%
	No fracture	0	23	

Knees		Full scall tests		Present collect
		Fracture	No fracture	
Simulations	Fracture	0	0	100%
	No fracture	0	24	

Tibias		Full scall tests		Present collect
		Fracture	No fracture	
Simulations	Fracture	1	0	100%
	No fracture	0	23	

From the results above, we judged that this simulation method enables us to evaluate the injury index of the dummy from start of impact to the point in time when the dummy strikes the ground. We judged that this computer simulation enables us to evaluate the risks and benefits of the airbag system using the 200 impact configurations defined in ISO/CD 13232.

EVALUATION OF INJURY REDUCTION PERFORMANCE OF AIRBAG FOR GL1800

ISO/CD 13232 defines the methodology for conducting the computer simulation of 400 impact cases, which are 200 impact configurations and with and without the proposed rider crash protective device. The combination of relative heading angles and contact points of 25 impact configurations are shown in Fig.23, and the differences in impact speeds are also defined.
In combination, the impact configurations become 200. In these 25 configurations, those configurations marked with **X** were omitted from simulation because the airbag did not deploy, or deployed but did not influence to the motion of riders or its injury index. Those configurations marked with a triangle were omitted from simulation because the airbag did not deploy from influences of impact speed. The injury index in the omitted configurations was defined, with and without airbag, as no differences of injury index.
The final calculation of the computer simulation was made using 121 impact configurations and 242 simulation cases.
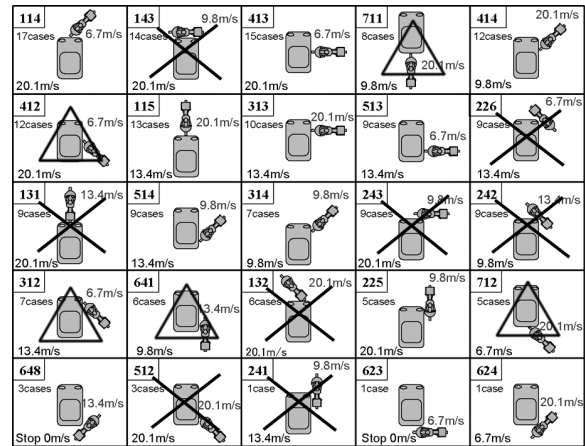

Figure 23. Impact configurations for computer simulation

Evaluation Results of Airbag System by Computer Simulation

121 impact configurations and 242 simulation cases were calculated. Injury reduction performance by the airbag was evaluated based on the methodology of ISO/CD 13232, including omitted simulation cases. As a result, the injury reduction performance of the airbag system, and its characteristics against various impact configurations were determined.

Rider's Injury Reduction Effectiveness

Figure 24 shows the results of the influence of airbags to injury during the primary impact sequence and secondary impact sequence in the area of the opposing vehicle where the dummy strikes. The vertical axis represents NIC values, (0 in NIC indicates the level without injury and 1 in NIC indicates level of equivalent of the fatal). Figure 24 shows the total average benefit and total average risk in the primary impact sequence. The total average benefit is 0.038 and total average risk is 0.001. The ratio of risk against benefit is 0.026. Also the average net benefit is 0.037. Figure 24 shows the total average benefit and total average risk in the secondary impact sequence. The total average benefit is 0.022 and total average risk is 0.011. The ratio of risk against benefit is 0.500. Also the average net benefit is 0.011. Consequently, the airbag system appears to provide a greater reduction of injury in primary impact sequence than in secondary impact sequence.
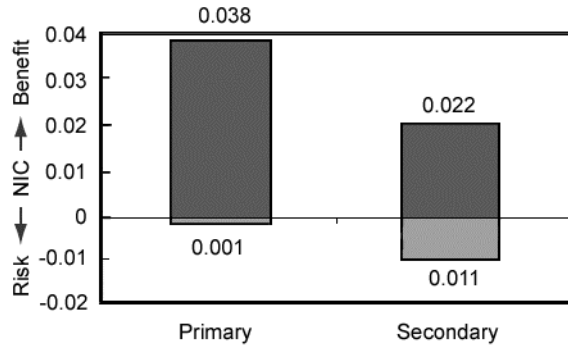
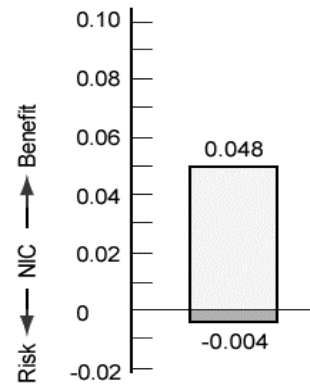**Figure 24. Total average benefits and risks, all calculation, primary and secondary impact sequence**

Figure 25. Total average benefits and risks, 200 impact configurations

Figure 25 shows the total average benefit and total average risk in the entire impact sequence. The total average benefit is 0.048 and total average risk is 0.004. The ratio of risk against benefit is 0.083. Also the average net benefit is 0.044. From these results, it was judged that the airbag system has appropriate injury index reduction performance.

Influence of Impact Speed

The average net benefit values were compared by impact speeds. Figure 26 shows their results. Impact speed in this case indicates relative speed. When colliding to the side of the opposing vehicle, the speed of motorcycles is used as the relative speed. When colliding to the front of the opposing vehicle, the combined speed of both vehicle speed is used as the relative speed. When colliding to the rear of the opposing vehicle, the speed of the opposing vehicle subtracted from motorcycle speed is used. When colliding to the front and rear of the opposing vehicle, and the impact configuration is angled, the impact speed of opposing vehicle is subtracted from the angled impact. For instance, in No.2 of configuration shown in Fig.1, the motorcycle collides into the front of opposing vehicle at an angle of 45 degrees. The relative impact speed in this case was calculated with "13.4m/s (motorcycle speed) plus 6.7m/s (opposing vehicle speed) times cos45° ".
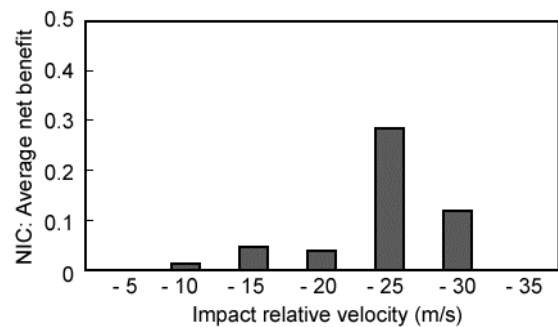

Figure 26. Aaverage net benefits by relative impact speed

Referencing Fig.26, the benefit of the airbag for the GL1800 is verified from low to high speed ranges, and thus judged effective. The highest benefit appears at the range from 20 to 25 m/s in the relative impact speed. Therefore, the effect of injury reduction is significant at a high-speed range.

An example of an impact configuration where the effect of airbags in a high-speed range appears clear is shown in Fig.27. Dummy motion during collision of the base motorcycle, without an airbag is shown in Fig.28. Dummy motion during collision of an airbag-equipped motorcycle is shown in Fig.29. In the base motorcycle, without an airbag, the head of dummy strongly impacts the roof of the opposing vehicle. In contrast, in the airbag-equipped motorcycle, the head of dummy softly impacts the opposing vehicle. The injury index is shown in Table 4. The injury index on the

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dummy is shown as AIS. AIS 1 is a minor injury level while AIS 6 is a fatal injury level. The injury indices are expressed in six steps. In the base motorcycle, without an airbag, AIS on the head was calculated as 6, i.e. fatal, whereas the calculated AIS on the head in the airbag-equipped motorcycle was representative of no injury. Similarly, the AIS on the neck in the base motorcycle without an airbag was AIS 4, whereas the AIS on the neck for the motorcycle equipped with the airbag was equivalent to no injury.
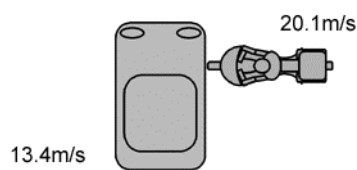
Table 4 Comparison of AIS between baseline and with airbag
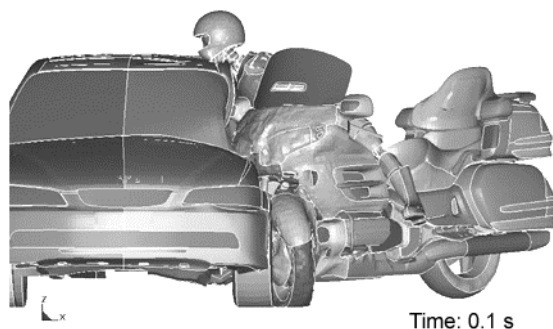
	Base line	Airbag
Head	6	0
Neck	4	0
Chest	1	1
Abdomen	0	0
Leg	3	3

Figure 27. Benefit impact configuration

Figure 28. Baseline impact case
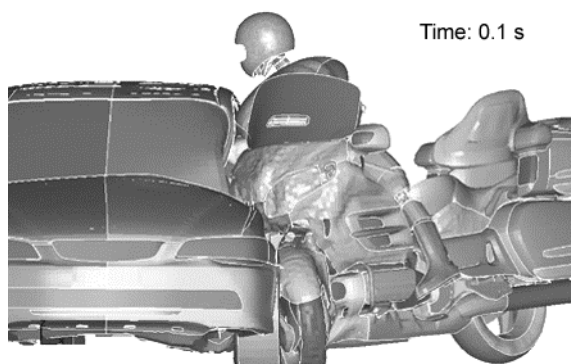
Figure 29. With airbag impact case

CONCLUSION

Computer simulation using the explicit method FEM software permits the evaluation of injury index on the dummy in entire impact sequence in the impacts between motorcycles and opposing vehicles. Using this simulation method, the injury reduction performance of an airbag mounted on the GL1800 was evaluated based on ISO/CD 13232.

The following conclusions regarding injury reduction are drawn from this research:

- The total average benefit was 0.048, risk was 0.004. The performance of the injury reduction system is appropriate.
- The highest average net benefit appears at the range from 20 to 25 m/s in the relative impact speed.
- The injury reduction effect when striking against opposing vehicle is greater than on impact with ground.

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